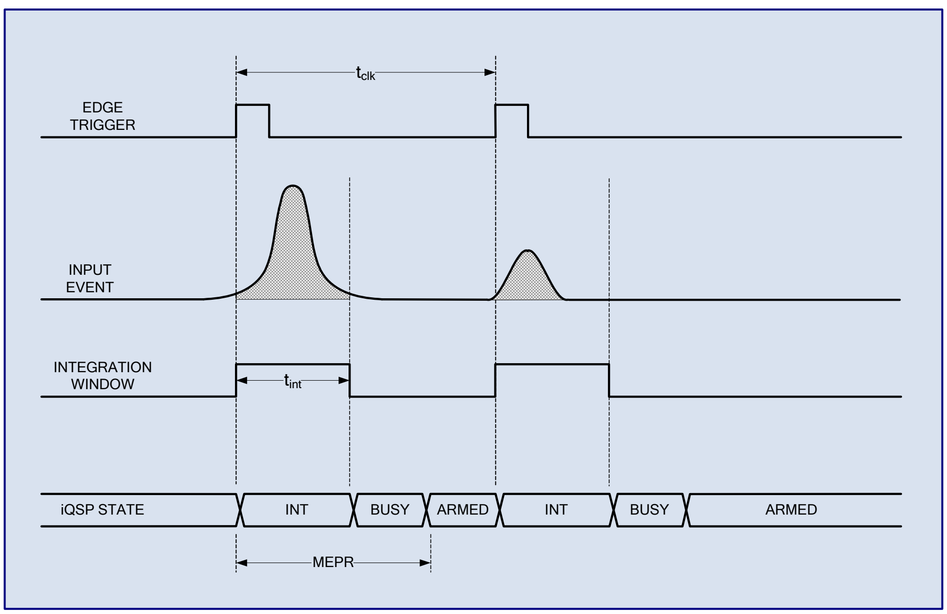
PhotoniQ: Speed and Throughput

Application Note

Speed and throughput of PhotoniQ multi-channel PMT data acquisition systems are characterized by three timing parameters, Minimum Event Pair Resolution (MEPR), Sustained Average Event Rate (SAER), and Maximum Trigger Rate (MTR). Although not strictly a timing specification, a fourth parameter called Event Buffer Size (EBS) indirectly affects system speed and throughput. To appreciate how these parameters determine system performance, it is helpful to understand their definitions and how they relate.

MEPR is a measure of the peak event rate that can be attained by a PhotoniQ system when in the *Particle* acquisition mode. Thought of another way, this is the minimum time allowable between two consecutive events such that each can be reliably acquired and distinguished from the other. The figure below shows an edge triggered example where two events are captured by the PhotoniQ. Notice how the *integration* (INT) and *busy* (BUSY) periods — which directly affect the MEPR specification — have ended and the PhotoniQ has returned to its *ready* state (ARMED) before the trigger for the second event occurs. Two closely spaced events can be acquired only when the time between the triggers for each event is greater than the MEPR. If this condition is not met, the second trigger is ignored by the PhotoniQ and the event is missed.



MEPR Definition

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Because of bandwidth constraints (MBytes/sec) at various points in the system, acquisition at the peak event rate cannot continue indefinitely. While several consecutive events spaced in time by the MEPR can be acquired and processed by the PhotoniQ, the average throughput through the system will always be less than or equal to what the MEPR might imply. The SAER is the metric that specifies the sustained average throughput and is strongly dependent on system configuration. It is a measure of the average rate at which events can be indefinitely acquired by the PhotoniQ. If the actual average event rate exceeds the SAER, the system will not have completed processing of the existing event before a new event enters the system. The result is that the PhotoniQ issues an internal *busy* signal that holds-off the acceptance of any new events until the processing on the current event is complete. A small amount of buffering in the PhotoniQ allows it to accept several consecutive events that briefly exceed the SAER specification.

The SAER and MEPR are typically used to characterize the performance of particle analysis systems where the event interarrival process is stochastic and often follows a Poisson distribution. The SAER is compared to the particle average flow rate which is usually adjusted so that it is less than the SAER for the system. Similarly, the MEPR is compared to the minimum resolvable particle spacing. The random interarrival nature of the particles makes it impossible to resolve all particles because a certain percentage of them will occur at an interarrival time that is less than the MEPR. Nevertheless, a statistical analysis can be performed using the particle average flow rate and the MEPR to determine the percentage of particles that are missed because they are too closely spaced. Adjustments to the flow rate and system parameters (namely integration time) can thus be made to achieve an acceptable percentage of missed particles.

The actual achievable Event Pair Resolution (EPR) for a PhotoniQ approaches the MEPR under conditions where the integration period, t_{int}, is less than 10% of the MEPR. For instance, if the specified MEPR for an IQSP580 is 2.5 usec, then the integration period must be less than 250 nsec to attain an EPR equal to the MEPR. When the integration period is greater than 250 nsec, the EPR is equal to the integration time plus 0.90 times the MEPR. For very long integration periods the EPR approaches the integration time.

The reciprocal of the EPR defines the maximum rate at which events can be acquired. Each event generates a block of data that is dependent on the number of channels configured. The block size in 8-bit bytes is simply the number of channels times two (16 bits per channel) plus overhead bytes. The actual number of overhead bytes depends on the software switch settings but a typical 32 channel system generates about 82 bytes per event while an 8 channel system generates about 22 bytes per event. Considering again the previous example where the system is continuously operating at an EPR of 2.5 usec, the average input event rate is nearly 400,000 events per second. This rate produces data at a rate of 32.8 MB/sec for the 32 channel case and 8.8 MB/sec for the 8 channel case. As mentioned previously, bottlenecks within the PhotoniQ, at the USB port, and in the PC itself, prevent this rate from being sustained. In actuality the PhotoniQ and its USB port are capable of transferring about 5.3 MB/sec continuously. Assuming the PC and its USB port can handle this data flow rate, the achievable SAER for the 32 channel configuration is about 65,000 events per second, not 400,000 events per second as the EPR might suggest. However, because the event data packet for an 8 channel configuration is almost four times smaller than that of a 32 channel, a SAER of 240,000 events per second is achievable for this configuration. Although certain user defined functions may reduce the SAER, the standard function set including background subtraction and gain compensation are performed in real time and thus have minimal negative affect on throughput.

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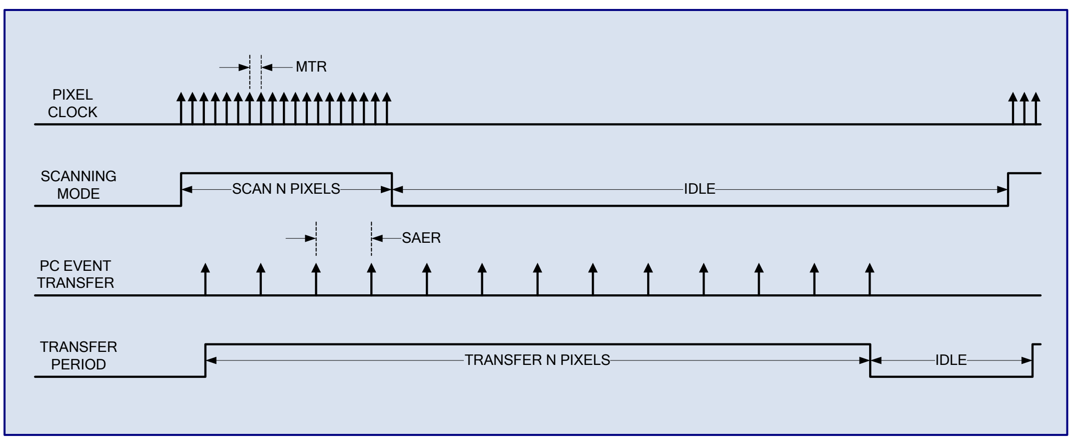
The MTR is a figure of merit used to characterize the system speed of a PhotoniQ in *Image* acquisition mode. Defined simply as the maximum event trigger rate, this is the maximum pixel clock rate that can be applied to the system. Since scanned imaging systems normally have a somewhat continuous and uniform event rate (i.e. pixel rate), the MEPR specification is not relevant because it applies only to brief bursts of closely spaced events like those found in particle analysis systems. The MTR on the other hand, specifies the *quasi-sustained* maximum trigger rate to the PhotoniQ. While large amounts of pixels can be acquired in short periods of time, this trigger rate cannot continue indefinitely because an event buffer in the PhotoniQ will allow the system to accumulate data up to the point in which the buffer is full. Beyond this point events are rejected. The EBS specification is therefore important so that the buffer can be appropriately sized to hold all events (pixels) before the pixel clock terminates. Events in the event buffer are transferred to the PC at a rate equal to the SAER. Usually in a scanned imaging system the pixel clock rate is much higher than the SAER. For this reason, once the image scan is complete, the scanning must remain idle long enough so that the entire image stored in the PhotoniQ's event buffer can be transferred to the PC.

The figure below depicts the timing of a scanned imaging system. During the *scanning mode*, the pixel clock continuously triggers the PhotoniQ and a total of N pixels are acquired by the system and stored in the event buffer. The figure shows the system operating at the maximum pixel rate because the pixel clock is equal to the MTR. Under these conditions the scan period is N / MTR seconds. As soon as the first pixels are acquired by the PhotoniQ, the system begins to transfer them to the PC. Although the figure shows the transfer rate occurring at the SAER, in actuality when the PhotoniQ is triggered at the MTR, it is too busy to transfer many pixels while acquiring data. Consequently, the bulk of the event transfer occurs while the scanning is idle and the transfer rate is equal to the SAER. The total event transfer time is therefore approximately equal to N / SAER seconds.



MTR Definition

As an example consider a confocal microscopy application where a 32 channel, 512 by 512 pixel image is scanned at the MTR. For this image size, a PhotoniQ IQSP580 (whose MTR is equal to 390KHz) will acquire the entire image in under one second and store it in its event buffer which at a minimum must hold 256K events. The PhotoniQ IQSP580 is available with an EBS of 500,000 events or 1,000,000 events — either of which would be suitable for this example. A lower cost IQSP580 that has no event buffer is also available but is mostly used in particle analysis applications where event buffering is not required. At the end of the scan period, the IQSP580 transfers the contents of the buffer to the PC at a SAER of 65,000 events per second. The transfer period takes four seconds and thus the entire image scan and transfer process takes a total of five seconds.

The capabilities of the PC can further limit the sustained throughput. In particular, the amount of RAM memory, the USB type, and the hard drive speed are the most important determinants of sustainable system event rate. For high performance applications, care should be taken when choosing a PC to operate with the PhotoniQ. Logging data to a file over a network connection is not recommended. In general this can reduce the maximum sustained event rate by a substantial amount. Logging data while running the real time display in the graphical user interface will also greatly reduce the captured event rate.

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